Final Technical Report

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Variations of Kuroshio Intrusion and Internal Waves at Southern East China Sea: Observational Study with Lagrangian Float and Mooring ADCPs

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The PI attended three ONR workshops to discuss and help define the future integrated observational program for the "Quantifying, Predicting and Exploiting Uncertainty (QPEU), more specifically to help formulate an experiment to study the Kuroshio intrusion, nonlinear internal waves (NLIWs), internal tides, inertial waves, and turbulence mixing resulting from the Kuroshio-topography interaction. Figures 1 and 2 illustrate where the Kuroshio and barotropic tides interact with the continental shelf of the East China Sea (ECS) and with one prominent submarine ridge (I-Lan Ridge). The experiment plan proposed by the PI included two components: 1) for the extended observational program, 3 months in the southwest monsoon, deploy an array of six 75-kHZ Long Rangers with thermistor chains; 2) for the 0.5-month intensive observational program on the continental shelf, overlapping with the extended observational program, collaborate with Thomas Sanford to make EM-APEX float observations (see Figure 2).

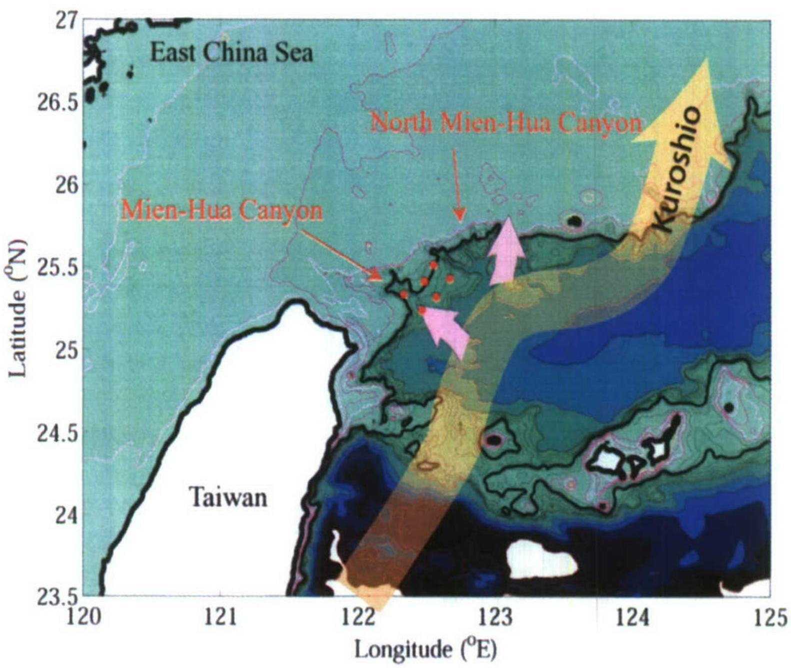

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***Figure 1:** Bathymetry map of the Southern East China Sea. The contour interval is 100 m between 0 and 1000-m depth and is 500m for depth greater than 1000 m. Thick solid curves indicate 0 and 500-m isobaths. The Kuroshio main path and intrusion paths are illustrated. Six dots mark the location of the proposed ADCP moorings.*

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14. ABSTRACT
The PI attended three ONR workshops to discuss and help define the future integrated observational program for "Quantifying, Predicting and Exploiting Uncertainty (QPEU), i.e., to help formulate an experiment to study the Kuroshio intrusion, nonlinear internal waves (NLIWs), internal tides, inertial waves, and turbulence mixing resulting from the Kuroshio-topography interaction. Using historical CTD data collected by the National Center for Ocean Research (NCOR) between 1985 and 2002, the PI computed the fluctuations of sound speed in different regions along the Kuroshio path and across the continental shelf and slope. Preliminary analysis concludes that strong sound speed anomalies are induced by NLIWs, internal tides, and processes associated with the Kuroshio interaction with the continental slope and shelf. Such sound speed anomalies have the temporal and spatial scales and characteristics associated with the corresponding oceanic processes.

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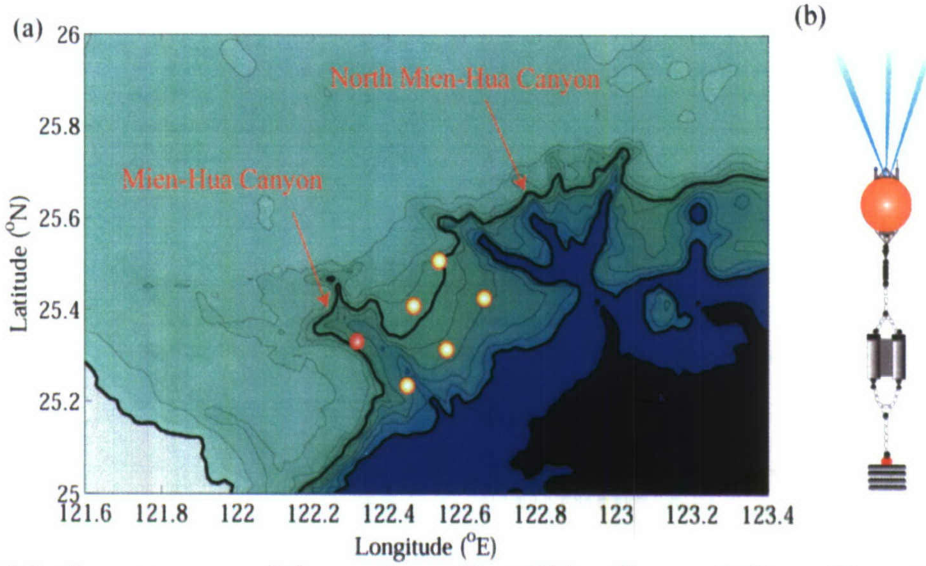

Figure 2: (a) bathymetry map of the southern East China Sea, and (b) configuration of bottom mounted ADCP. Six bullets in panel (a) indicate the positions of the proposed ADCP moorings. The red bullet indicates the position of ADCP deployed in July 2007.

In July 2007, the PI deployed a bottom-mounted Long Ranger ADCP on the slope of the Mien-Hua Canyon at 600-m depth (Fig. 2). The location was chosen where numerical models suggest strong internal tides (Jan, personal communication) and possible Kuroshio intrusion (Lermusiaux, personal communication). Unfortunately this mooring was lost after two typhoons passed by the area.

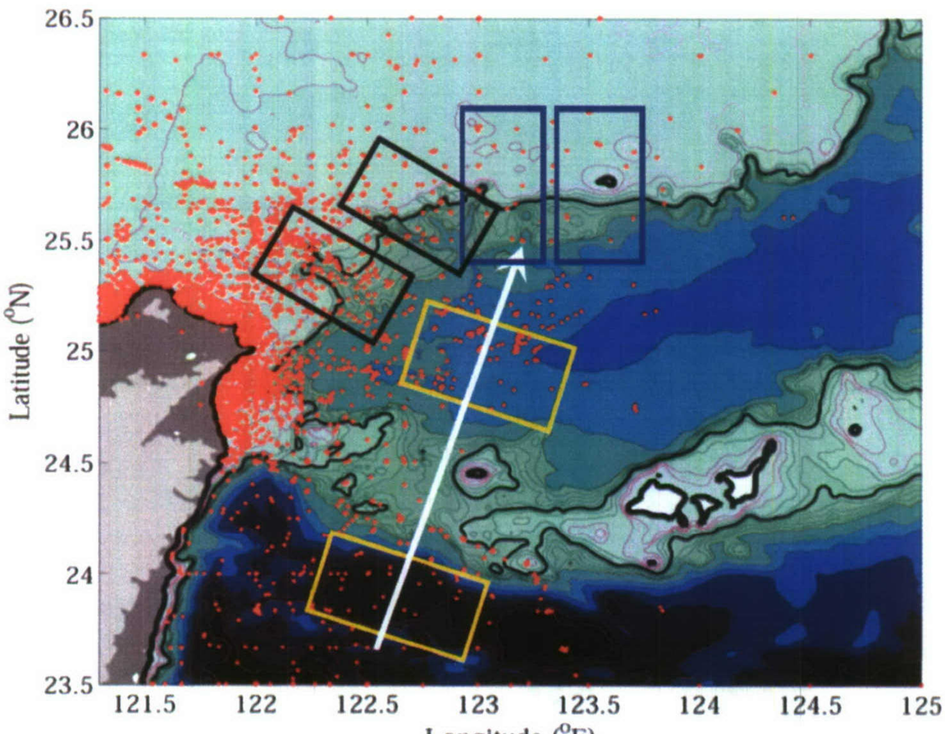

Figure 3: Locations of historical CTD (red dots) and area sections where CTD data are used for computing the sound speed anomaly.

Additional salary funds were provided for the PI to analyze a set of ADCP observations, the only fast-sampling ADCP data set available for studying high-frequency NLIWs. However, the focus of the analysis was guided to examining the sound speed anomaly using the historical CTD data from the area, including effects of internal waves, tides and Kuroshio. Using historical CTD data collected by the National Center for Ocean Research (NCOR) between 1985 and 2002, the PI computed the fluctuations of sound speed in different regions along the Kuroshio path and across the continental shelf and slope (Fig. 3).

Standard deviations of sound speeds averaged in the areas north and south of I-Lan ridge are shown in Fig. 4. A band of strong standard deviation extending from the surface to ~200 m in the north of I-Lan ridge might represent the effect of the migration of the Kuroshio front. A deeper band near 400-m depth may be associated with the base of the Kuroshio. The strong sound speed anomaly is also found in the upper ocean, likely associated with the change of the thermal structure in the surface mixed layer.

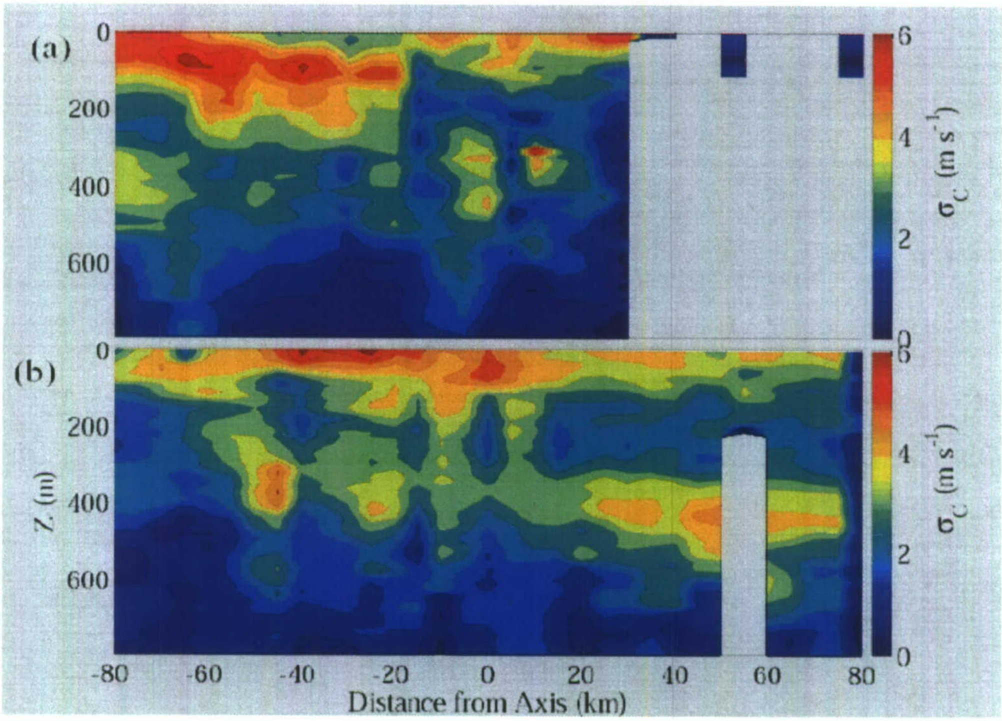

Figure 4: Standard deviations of sound speed averaged over sections at (a) north of I-Lan Ridge (the top yellow box in Figure 3), and (b) south of I-Lan Ridge (the bottom yellow box in Figure 3).

The Kuroshio interaction with the continental slope and shelf could lead to large fluctuations of sound speed (Fig. 5). A ~100-km horizontal band of strong sound speed anomaly is found emanating from the continental shelf break of SECS. Small patches of large sound speed anomaly on the continental shelf may be associated with NLIWs.

Above Mien-Hua Canyon and North Mien-Hua Canyon, the largest sound speed anomaly is found with the maximum standard deviation about 10 m s^{-1} (Fig. 6). We attribute this anomaly to NLIWs often found in satellite images.

The sound speed anomaly induced by oceanic processes in the SECS is summarized in Fig. 7. The Kuroshio interaction with the continental shelf and slope introduce the sound speed anomaly (standard deviation) about 5 m s^{-1} which decays with depth. Such sound speed anomaly has the horizontal scale of O(10s-100 km). NLIWs on the continental shelf may introduce the sound speed anomaly as large as 10 m s^{-1} with the horizontal scale O (1km) in a short time scale O(10s min). In comparison, NLIWs found in the Philippine Sea generate much weaker sound speed anomaly. Internal tides also cause sound speed anomaly as large as 5 m s^{-1} centering at the thermocline.

Preliminary analysis concludes that strong sound speed anomalies are induced by NLIWs, internal tides, and processes associated with the Kuroshio interaction with the continental slope and shelf. Such sound speed anomalies have the temporal and spatial scales and characteristics associated with the corresponding oceanic processes. To quantify, predict, and exploit the uncertainty of the acoustic propagation and sonar performance, we need to understand the dynamics of these responsible oceanic processes and their effects on the sound speed. This is the main goal of the proposed QPE experiment.

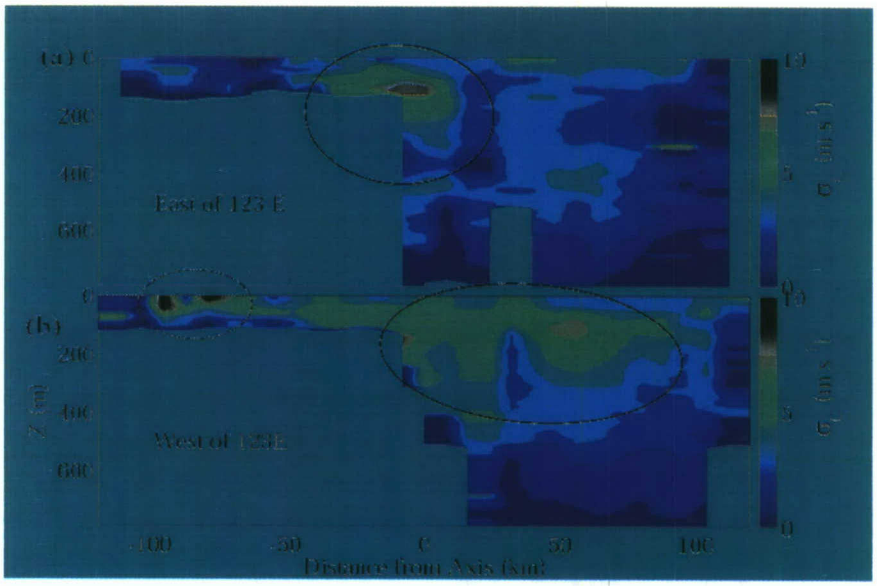

Figure 5: Standard deviations of sound speed averaged over sections across the continental slope and the continental shelf on the main path of Kuroshio at (a) east of 123 °E (the right blue box in Figure 3) and (b) west of 123 °E (the left blue box in Figure 3).

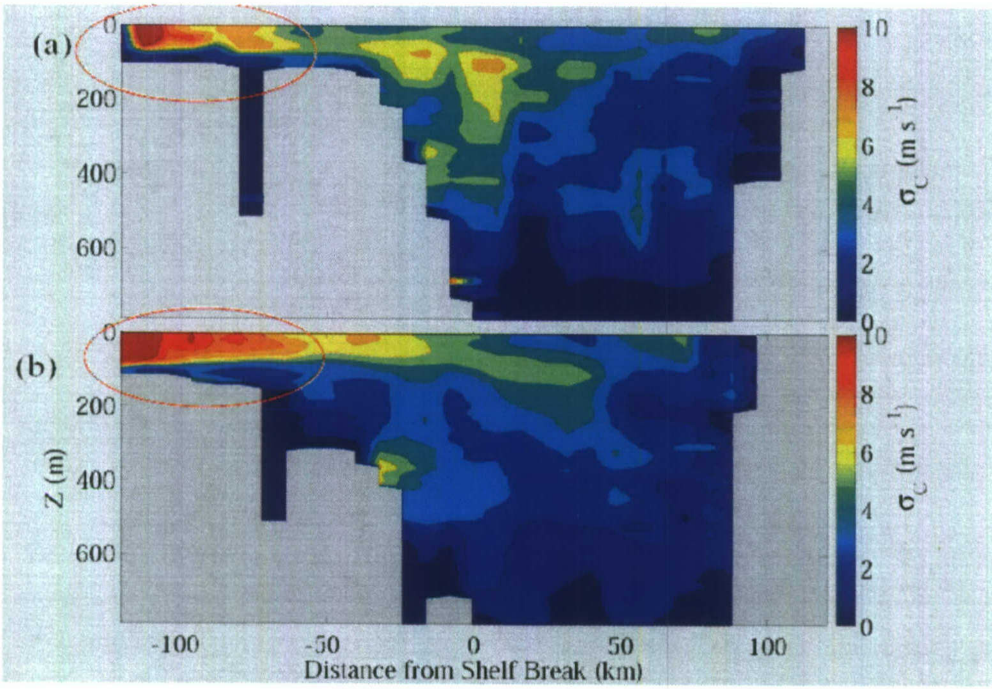

Figure 6: Standard deviations of sound speeds averaged over sections across the continental slope and the continental shelf on possible intrusion paths of the Kuroshio centering around (a) North Mien-Hua Canyon (the top black box in Figure 3) and (b) Mien-Huan Canyon (the bottom black box in Figure 3).

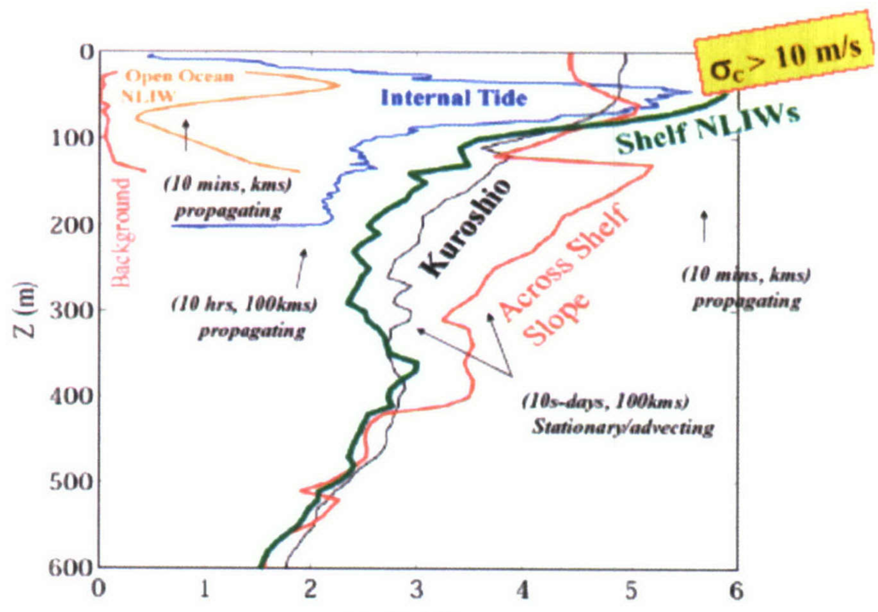

Figure 7: Summary of the sound speed anomaly introduced by primary oceanic processes along the Kuroshio path near the southern East China Sea. Typical temporal and spatial scales and characteristics of oceanic processes are labeled. The standard deviation of sound speed associated with NLIWs on the continental slope exceeding 10 m s^{-1} is highlighted.